Hydrodynamics and evaporation of a sessile drop of capillary size

L.Yu. Barash

Landau Institute for Theoretical Physics
142432 Chernogolovka, Russia

October 19, 2010

Abstract

Fluid dynamics video of an evaporating sessile drop of capillary size is presented. The corresponding simulation represents the description taking into account jointly time dependent hydrodynamics, vapor diffusion and thermal conduction in an evaporating sessile drop. The fluid convection in the drop is driven by Marangoni forces associated with the temperature dependence of the surface tension. For the first time the evolution of the vortex structure in the drop during an evaporation process is obtained.

1 Introduction

Evaporation of a drop in an ambient gas was considered since Maxwell time mainly as diffusion of vapor from a near-surface layer. On the other hand, fluid flows inside a sessile drop driven by thermocapillary forces during the evaporation process have been studied in detail only recently, even in the quasistationary limit. We have carried out for the first time the numerical simultaions that provide time dependent fluid convection, vapor diffusion and temperature distribution in an axially symmetrical evaporating sessile drop of capillary size [1, 2, 3]. Thus, our results allow, in particular, to observe the fluid dynamics including the time evolution of the vortex structure of Marangoni convection as it develops in an evaporating sessile drop.

The particular conditions and parameters of the simulation correspond to experimental conditions of evaporating toluene drops on silicon nitride substrate described in [1]. Due to high thermal conduction of silicon nitride,

the boundary condition for the temperature distribution at the substrate can be reduced to the constant room temperature. The vapor diffusion outside the drop results in inhomogeneous mass flow from the drop surface, which in turn results in the inhomogeneous temperature distribution in the drop and on the drop surface. Marangoni forces associated with the temperature-dependent surface tension induce the fluid flows inside the viscous drop.

In the linked video, we have used the simulation described in [1, 2] to study the evaporation process of a sessile drop of capillary size. Several dynamical stages of the Marangoni convection of an evaporating sessile drop are obtained. The stages are characterized by different number of vortices in the drop and the spatial location of vortices. As seen in the video, during the early stage the array of vortices arises near a surface of the drop and induces a non-monotonic spatial distribution of the temperature over the drop surface. The number of near-surface vortices in the drop is controlled by the Marangoni cell size, which is calculated similar to that given by Pearson for flat fluid layers. The number of vortices quickly decreases with time, resulting in three bulk vortices in the intermediate stage. The vortex structure finally evolves into the single convection vortex in the drop, existing during about 1/2 of the evaporation time.

2 The video

The video showing the evaporating sessile drop can be seen at the following URLs:

- Video 1 – Low resolution
- Video 2 – High resolution

This video has been submitted to the *Gallery of Fluid Motion 2010* which is an annual showcase of fluid dynamics videos.

References

[1] L.Yu. Barash, T.P. Bigioni, V.M. Vinokur, and L.N. Shchur, *Evaporation and fluid dynamics of a sessile drop of capillary size*, Phys. Rev. E **79**, 046301 (2009).

[2] L.Yu. Barash, L.N. Shchur, *Hydrodynamics of evaporating sessile drops*, e-print arXiv:1008.4123 (2010).

[3] L.Yu. Barash, *Influence of gravitational forces and fluid flows on the shape of surfaces of a viscous fluid of capillary size*, Phys. Rev. E **79**, 025302(R) (2009).